U. S. DEPARTMENT OF AGRICULTURE

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PUMPING FROM WELLS for IRRIGATION

MANY THOUSANDS of farmers in the arid and semiarid States have no dependable water supply except what can be secured from the underflow. Large areas of land now devoted to grazing may and doubtless will be eventually devoted to intensive farming by the utilization of the underground-water resources. The sinking of a well which will produce an ample supply of water and the installation of an efficient and economical pumping plant require skill and knowledge not ordinarily possessed by the farmer. The purpose of this bulletin is to guide aright those interested in pumping from wells for irrigation by making available the most essential information pertaining to well construction and the selection, installation, and operation of pumping plants.

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PUMPING FROM WELLS FOR IRRIGATION.[1]

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INTRODUCTION.

LESS than 2 per cent of the total land area of the arid and semi-arid sections of the United States is now irrigated, yet reclamation has reached the stage where future progress can be made only through the construction of extensive storage works or the use of underground waters. As storage works require large investment of capital, which implies some form of community effort, the only opportunity for further advance as a result of individual initiative lies in the recovery of underground water.

Water pumped from underground sources is destined to play a more important part in the irrigation of land in the United States than it has hitherto, but it is well for the individual to bear in mind that not every underground supply is suitable for irrigation in quality or quantity.

The following considerations should have attention before money is spent for a well and pumping plant:

(1) Is the water suitable for irrigation?

(2) Is the underground water supply sufficient to meet the expected requirements?

(3) Is the pumping lift low enough to justify the expense of pumping for the crops to be grown?

(4) Have similar undertakings succeeded in the locality?

(5) Is the power supply to be used for pumping reliable and cheap?

(6) Have local business men, disinterested in the sale of pumping machinery or land, confidence in the feasibility of pumping for irrigation?

Besides considering these matters which have particular connection with irrigation by pumping, the farmer has also to give thought

[1] A compilation of contributions by F. L. Bixby, C. E. Tait, and Milo B. Williams, senior irrigation engineers; J. C. Marr and L. M. Winsor, irrigation engineers; P. E. Fuller, former irrigation engineer; and Prof. F. J. Veihmeyer, collaborator. Free use has been made of data and statements in publications of various State agricultural experiment stations.

to other general phases of irrigation, such as the necessary preparation of the land, the adaptability of the soil for irrigation, the climate, the accessibility of markets, and the rates charged locally on borrowed money. These are discussed in other bulletins of the department.[2]

SUMMARY.

The essentials of a satisfactory irrigation pumping plant using well water are: (*a*) An ample supply of water suitable for irrigation and near enough to the surface for economical pumping; (*b*) a pump which is adapted to the given conditions as to lift and quantity to be pumped; (*c*) an engine or motor that will deliver the required power to the pump with the minimum loss of efficiency and at the minimum cost; (*d*) the entire plant carefully planned and installed.

The farmer should engage the services of a reliable well driller and should see that a well-drilling contract is drawn up which will protect him against unwarranted expense and inferior work.

The well casing should be of a standard type, such as screw, riveted, or stovepipe casing, and the portion in contact with water-bearing formations should be perforated so as to admit water in sufficient quantities and screen out the sand and gravel.

Before pumping equipment is purchased the well should be thoroughly tested to determine its capacity and draw down.

The types of pumps most commonly used for irrigation are the horizontal and vertical centrifugal, the deep-well turbine centrifugal, the plunger, and the air-lift. The height through which the water is to be raised is the chief governing factor in the selection of the type.

The power may be supplied by an electric motor or an internal-combustion engine.

QUALITY OF THE WATER.

Certain dissolved minerals constituting what are known as alkali salts are sometimes present in well water in sufficient quantities to be injurious to vegetation. If there is any question as to the quality of the water an expert opinion should be obtained from the State agricultural college. Some crops are more tolerant of alkali salts than others, and this fact should be remembered when considering the suitability of water for irrigation.

WATER SUPPLY.

The amount of water required varies with the nature of the crop, the soil, the method of irrigation, and the climatic conditions. Deciduous fruit trees and vines require the smallest quantity. Forage crops and garden truck require the most. The range is from less than 1 foot to about 4 feet in depth a year. A close estimate of the depth required can best be made by observing the irrigation practice of the locality, but if there is no good example at hand results obtained under similar conditions in other sections may be taken as a guide.[3]

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[2] Farmers' Bulletins 863, 864, 899, 1243, 1517; Department Bulletins 1047, 1048; Department Circular 197; Monthly Weather Review; Field Operations of the Bureau of Soils.

[3] See Farmers' Bulletins 863, 865, 1517, and Department Bulletin 339 for discussions of the irrigation needs of various crops.

Before considering the adequacy of a well as a source of water, it is necessary to know the depth of water required at each irrigation and the frequency of irrigations in order that the maximum rate of use may be estimated. Suppose, for example, that 40 acres is to be set out in fruit trees and that it has been found by a study of other irrigated orchards that an application 6 inches deep must be made during a certain time of the year within a period of 10 days, representing the maximum rate of irrigation. The well must then be able to supply 20 acre-feet during a period of 10 days continuous pumping, or in other words, the well must produce at the rate of approximately 1 cubic foot of water per second, or about 450 gallons per minute.

Unless an ample supply of underground water is known to exist, as evidenced by the successful operation of large pumping plants in the vicinity, each water-bearing stratum should be tested carefully during the boring of the first well. The ideal irrigation well is one which lowers 10 or 15 feet during the maximum rate of pumping, but returns within a foot or so of the original level a short time after the pump is stopped. There is, of course, a seasonal fluctuation of the water level independent of that caused by pumping, but unless the yearly demand exceeds the supply the water should return to its normal level or nearly so before the beginning of each irrigation season. A discussion of well testing will be found on page 9.

The possibility of obtaining a dependable water supply from wells is difficult to determine in any way except by sinking test wells. The Department of Agriculture places no credence whatever in "water-witches."[4] On high, arid or semiarid plateaus far removed from mountains and large rivers and with good surface drainage it is not likely that water will be encountered at any depth feasible for pumping. Prehistoric lake beds, such as are often found in the Great Basin area, rarely yield a good flow of water, as the gravels are in thin strata, generally interspersed with strata of clay and fine silt. On the other hand, in the valley of a large river with a sandy bed and on the adjacent benches or mesas the chances for striking water in sufficient quantities for irrigation are very favorable. The same is often true of a plain surrounded by high mountains and having no surface drainage or of a desert valley traversed by a wide, dry, sandy river bed carrying spring floods and occasional freshets.

A flow of 300 to 500 gallons of water per minute usually is considered an easily handled irrigation stream, but if less than 300 gallons is secured a small storage reservoir,[5] which may be filled during the night, will provide the necessary stream for the next day's irrigation if the pump continues to operate. Larger supplies often are furnished by a single well, or from batteries of wells pumped from one central station.

THE PUMPING LIFT.

The lift against which water for irrigation may profitably be pumped varies with the value of the crop to be grown. Under exceptional conditions water is lifted profitably 500 or more feet.

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[4] See Farmers' Bulletin 1448, Farmstead Water Supply.
[5] See Farmers' Bulletin 828, Farm Reservoirs.

The last Federal census of irrigation reported an average pumping lift of 41 feet for many thousand plants throughout the West. The cost of pumping varies with the distance through which water is raised. It is best to avoid the possibility of failure by undertaking to pump water only where such ventures have proved profitable for the particular crop and locality.

LOCATION OF THE WELL.

If possible, a topographical survey should be made to locate the proper site for the plant and permit the laying out of a field system of distributing ditches or pipes. The pump should be located at the highest point of the land from which water may be conveyed economically through the ditches to all parts of the field, unless conveyance through pipe lines is planned, when a lower and more central location may be more desirable.

THE WELL CONTRACT.

Ordinarily the boring or digging of an irrigation well is provided for by formal contract to insure efficiency of performance by the well driller. The following suggestions, pertaining in the main to a well drilled by percussion methods, should have the attention of a farmer entering into such a contract.

A contract may specify the character of the apparatus to be used in sinking the well. There should be a difference of at least 2 inches between the outside diameter of the sand bucket and the inside diameter of the casing and the sand bucket should have a steel shoe with a flap valve of as great an area as the bucket will allow. Often a driller's outfit will include a dilapidated bucket possibly three or four inches in diameter and having a round, worn-out soft iron shoe, with a small valve in the bottom which is hardly one-half the size the bucket will allow; and, if permitted, he may attempt to sink a well 10 inches in diameter with the bucket.

In some sections of the West, it is customary for the well driller to furnish casing, starter section, and strainer, if one is used. If the casing is of the stovepipe type the gauge and quality of steel used, whether the casing be single or double, should be specified in the contract. The construction of the starter section should be set forth in detail, as should also the thickness of the drive shoe and the material of which it is made, its shape and temper, the gauge of casing and the length of sections used in the starter section and the manner of joining these together. The dimensions of the well should be set out, and the length and spacing of the perforations or the characteristics of the strainer described.

There are several ways of paying for such work. The usual way is at so much per foot for drilling, the scale of prices increasing with the depth of the well. It is usually specified that the first 25 feet shall be paid for at a flat rate per foot, with an increase per foot for the next 25 feet and so on to the full depth of the well. Most well drillers insist on inserting in the contract a provision for minimum depth of well, and as a protection for the farmer the maximum depth should be specified, so that the driller may not deliberately pass a desirable water-bearing stratum and drill to greater depth for the increased pay.

Several large well-drilling companies work for a specified sum per day for the use of the well-drilling rig. No charge is made for the time consumed in making repairs. Another arrangement specifies a lump sum for the drilling of a well of certain size to a definite depth. In such an arrangement the well driller usually sets his prices to protect himself, with more than necessary safety. Generally he can make a closer estimate of the probable depth of the well than the farmer. The extra chance he runs in contracting for definite quantities of water is reflected in his price. Such arrangements often have led to much dispute.

A precaution the farmer should take in entering an arrangement of the "no-water-no-pay" type is to insist that the draw down of the water surface in the well during the pumping test shall not exceed a specific limit, and that the test be continued long enough so that the accumulated head of water in the immediate vicinity of the well shall be removed, leaving only the normal supply which will come to the well after a long period of pumping.

The test should last long enough to clear the water. Inability to do this usually indicates improper perforation of the casing, an unsuitable strainer, or the collapse or rupture of the casing. The contract should call for the delivery to the farmer of a complete and detailed log of the formations encountered in sinking the well.

When working under contract the driller should be required to furnish bond or to advance all materials and labor, and should not receive payment for partial completion of the work. This protects the farmer in case it is necessary, through carelessness or mishap for which he is not to blame, to abandon the well and all or part of the casing. Usually it is advisable to set a time limit for the completion of the well.

In case it is anticipated that a turbine pump or other close-fitting machinery will be inserted in the well, the contract should specify that the bore of the well shall be straight enough to receive the machinery; or it may stipulate a minimum clearance between pump shell and inside of casing when the pump is in place.

WELL CASING.

Stovepipe casing is used in many water-bearing formations, but most successfully where coarse, unconsolidated materials are encountered. To avoid use of a strainer, the casing is perforated after the well is completed by tools which cut longitudinal slits or gashes from the inside. Screw casing also may be perforated and has the advantage over other casings that it may be pulled if the well is found to yield insufficiently. It is especially adapted to open-bottom wells in which it may be necessary to draw back to a certain formation after going beyond the desired depth, and may also be used in the sinking of wells, especially those of 12-inch diameter or smaller, where a strainer is to be inserted and the outer casing withdrawn.

Riveted casing is especially adapted to coarse-sand and small-gravel formations where driving or forcing is not necessary and where the water-bearing stratum is known to be unusually thick.

It may be perforated more effectively than screw casing, but it will withstand only a limited amount of perforation.

STOVEPIPE CASING.

Stovepipe casing consists of 2-foot sections and is usually made of steel sheets, with rivets spaced longitudinally of the section 2 or 2½ inches apart at the ends to 3 or 4 inches apart at the center. Each section of this casing, after being riveted, is placed in a machine or lathe and rotated against a facing tool to "true" the ends. For insertion in the well, a casing is assembled in short lengths as the well is drilled, but must be used double, there being a slight difference in the diameter of the inside and outside sections. An end joint of the inside section thus occurs midway of the outside section. Hence, when the lengths are together, the end faces butt evenly and squarely against each other and are held from slipping or telescoping by each other. Sometimes, as the lengths are assembled, they are profusely dented from the outside by a pick and are so kept from slipping apart or separating in the well in case the drilling tool should hang on the casing or on the shoes. Sometimes the sections are riveted together as a like precaution.

Stovepipe casing may be obtained in all diameters from 6-inch to 26-inch or larger. The 16-inch size is most used in irrigation wells.

A starter, usually consisting of eight 2-foot sections of casing of double or triple thickness riveted together and then to a drive shoe, forms the first section upon which rests the "string" of casing. If the material is fine and contains no bowlders or hard material, the 2-ply, 16 to 10 gauge starter, will be ample; otherwise the starter should be 3-ply. The drive shoe is slightly larger in outside diameter than the following casing, so cutting the hole larger than the casing and giving it clearance.

The drive shoes used with stovepipe casing are usually larger and heavier than those needed for other casing and have a shank which is riveted to the casing; the latter slips over the shank and butts against a shoulder on the outside of the shoe. Sometimes this casing is driven, for which operation a drivehead is used. This is composed of a heavy cast or wrought steel cap, recessed so as to fit the top of the casing snugly, and a pair of heavy clamps is bolted to the drill stem, which is raised and allowed to fall, as in the drilling stroke, the clamps striking the drivecap. Such casing has been put down as far as 200 feet in heavy bowlder formations by driving, though it is generally believed that it can not be sunk except with hydraulic jacks or levers, sometimes called "pries," which exert a steady and uniform pressure. Generally the use of hydraulic jacks is to be preferred to driving.

Stovepipe casing is likely to pull apart in fine sands unless it is riveted before being sunk. To prevent this a substantial footing for the casing must be found.

SCREW CASING.

Screw casings may be standard wrought-iron pipe with ordinary outside couplings. For heavy driving extra strong pipe, threaded to permit the ends to butt, and line pipe couplings should be used. "Inserted-joint" casing has one end of each length threaded inside after being expanded slightly, thus reducing the resistance when the casing is being lowered. Joints so made will stand very little driving. Casing may be obtained in a number of weights, such as light well casing, about half as thick as standard pipe, standard, and extra heavy pipe. When screw casing is used, whether with standard couplings or inserted joints, a steel drive shoe must be screwed or riveted to the bottom or upon the starting joint. Such a shoe should be of a thickness which will stand safely driving through hard strata or against bowlders. It is usually from three-fourth inch to 1 inch thick when used with large sizes of casing and from five-eighths to three-fourths inch thick for sizes below 10 inches.

RIVETED CASING.

Riveted casing, composed of rolled-steel sheets, in sections from 14 to 24 inches in length, and plain or galvanized to resist rust, is frequently used. It is inconvenient to handle and will stand only light driving, and generally must be forced down by hydraulic pressure or a lever. It is often used in diameters over 20 inches for pits or dug wells, the weight of iron being proportioned to the diameter and the depth of the well. This casing usually may be obtained locally, especially in galvanized iron, which may be made at sheet-metal shops. If of heavy iron it must be obtained from boiler or sheet-iron manufacturers at prices varying according to the gauge.

If heavy-riveted casing is used it may be strengthened at the joints, the weakest parts, by butting the ends together and using inside or outside collars riveted to each section. This precaution is necessary if the casing must be forced into a hard formation, and some kind of a drive shoe at the bottom will be needed to prevent battering of the casing by bowlders or hard material.

STRAINERS.

Strainers have had their principal use in fine sand formations, but it has been found that where the water-bearing strata are of sand so fine as to call for special strainers wells are likely to fail anyhow, and the expense of strainers added to their uncertain action has led to discontinuance of their use in many sections. Gravel inserted in the well around the casing is now frequently used successfully in place of a strainer at much lower expense. (See p. 8.)

If conditions seem to call for use of a strainer it should be of a type known to be successful in similar formations.[6] Some water may be pure enough for irrigation but still contain enough salt to corrode certain metals to the extent of closing the openings, so rendering the strainer useless, and this fact should also be kept in mind when considering the use of a strainer.

PERFORATIONS.

Wells may fail to supply the amount of water they are capable of yielding because of insufficient perforation of the casing. While no definite rule can be given, it is recommended that as many per-

[6] For a description of strainers, see Water-Supply Paper 257, U. S. Geological Survey, Well-Drilling Methods, by Isaiah Bowman.

forations as possible be put into the shell of the casing opposite the water strata without dangerously weakening the casing. As much as 40 per cent of the metal can be cut away, but the proportion must be varied according to the shape and size of perforations, determined by the materials to be screened. Three or four slits should be made in each ring or circle, a space of 3 or 4 inches skipped, and a second ring or circle of slits then made, staggered from the preceding set. Under any conditions the proper perforating of casing in place is difficult to effect, and it would be well for the farmer to request a visible test of the efficiency of the apparatus before an attempt is made to perforate the casing underground. Many wells which do not produce sufficient water after the first set of perforations is made are much improved by repeating the operation.

THE DOUBLE-CASING WELL.

The double-casing or gravel-screen type of well is often very satisfactory in certain sections of the West. In drilling this well a large temporary casing is used. After the well is drilled a profusely perforated casing is centered in the temporary casing and as the temporary casing is withdrawn a screen of fine gravel or crushed stone is placed around the inner casing (see fig. 3). The gravel or stone filling should extend to the surface. Usually the screen should be at least 6 inches less in diameter than the temporary casing, to insure ease of insertion. If it is necessary to be sure of placing a continuous covering of gravel around the permanent casing a space of at least 4 inches should be left between the screen and the outer casing when the former is in place; otherwise the gravel may clog in spots and be distributed unevenly.

When properly made this type of well has many advantages over the type in which the casing is perforated in place, chief of which is the material increase in open space per linear foot of well. Moreover, the gravel screen is useful in fine sand formations in holding back a portion of the sand and so preventing caving. The continuous screen of gravel insures free entry of every stratum of water, whereas in perforating a casing after it is in place the perforator may miss some of the water-bearing strata unless accurate records are kept during the drilling process and careful measurements are made during the perforating.

This device requires that the temporary outside casing be jointed strongly enough to permit pulling from the well. Stovepipe casing will not withstand this operation, but is sometimes used as the outer casing, being left in the well with the inner casing and the inclosed gravel screen. Where this plan is followed the outer casing, which is of large diameter (18 to 24 inches), is first sunk and perforated opposite the water-bearing strata. The inner casing may be of the stovepipe type or a jointed pipe which is perforated during manufacture; if stovepipe casing is used it likewise is perforated before insertion. Crushed gravel is inserted between the two casings after both are in place. This makes an expensive installation, but one which has proved successful in many instances. It has the special advantage in some formations of affording a double protection to the bowls of a deep-well turbine centrifugal pump, which might be lost or rendered ineffective by the distortion or collapse of a single casing as the result of caving.

THE OPEN-BOTTOM WELL.

Many successful irrigation wells have been obtained in stratified formations, such as are found in the interior valleys of California, by making what is commonly known as an open-bottom well. In this type of well the bottom of the casing is open and all or part of the water enters through this open end. Such a well often is improved by perforating the casing to admit water from some higher stratum in addition to that coming from below.

The condition most favoring an open-bottom well exists where the lowest water stratum tapped underlies a hard, impervious material, such as clay, hardpan, or sandstone, in which the casing can be embedded firmly to form a foundation for the column and act as a seal to prevent water from carrying sand down from above, outside of the casing. The presence of the impervious layer or layers is essential to the success of the well. As an added precaution the hole bored through the hard stratum should be at least 2 inches smaller in diameter than the casing.

The impervious stratum acts as a roof over the water-bearing stratum from which, if it is fine sand, the fine materials will be pumped out gradually until a large cavity is formed in the bottom of the well. Under such conditions it is necessary that the impervious stratum be hard and thick enough to prevent serious caving. Should the roof give way under test, it will be necessary to drive the casing through the water-bearing stratum and embed it in hard materials below. Perforations can then be made opposite the water and the open-bottom well will be changed to a closed-bottom well.

WELL DEVELOPMENT AND TESTING.

A very serious and common mistake is made by the purchase of pumping equipment before the well is developed and tested thoroughly. Often wells increase in capacity with the first pumping. This is especially true when the water-bearing material contains fine sand, clay, or silt which can be removed by pumping. Heavy pumping is therefore often desirable before a test is run. It is impossible for manufacturers to supply efficient pumping machinery without accurate information as to the conditions under which the plant must work, and they should be furnished with the following information when their estimates of cost are requested:

(1) Inside diameters of the well with lengths of each size of casing.

(2) Total depth of the well.

(3) Depth to water table below the surface of the ground, and an estimate of probable seasonal fluctuations.

(4) The vertical and horizontal distances water must be pumped from the surface in the well with kind of pipe to be used.

(5) Distances water will drop in the well when different quantities are pumped.

(6) Probable economical draw down and ultimate capacity of the well.

The first four factors can be ascertained from the driller's log of the well and by direct measurements, but factors 5 and 6 can be determined only by a pumping test. Two plans for testing wells are practicable:

Test Plan No. 1.

This is adapted to wells where the water level is 25 feet or less below the surface and general conditions indicate that, for the permanent installation, a horizontal centrifugal pump can be used on the surface or in a pit.

This test calls for a tractor or other temporary power, and a horizontal centrifugal pump sunk into a temporary pit in such way that a belt can be sloped to it from the tractor. A fair test of the average well may be obtained with a pump of about three-fourths the capacity of the permanent one. The smaller outfit will not develop a well as thoroughly as may be done by use of an oversized pump, but an accurate estimate of the rate of increased capacity per foot of draw down can be made, and from this information the proper economical draw down and final yield of the well can be estimated closely enough for designing purposes.

As the excavation and curbing are expensive, it is advisable for the farmer to put in a temporary curb. This may be 20 feet deep or less, to set the pump near the water table. A pump set about 5 feet above the water table is capable of handling a 15-foot draw down, which affords fair indication of future performance.

Test Plan No. 2.

This is adapted to wells where the water table is 20 feet or more below the surface and general conditions indicate that the draw down will increase the lift to approximately 50 feet or more. It calls for a deep-well turbine pump or an air-lift outfit. Occasionally the best equipped well drillers have outfits of this kind, and where they are readily available plan No. 1 should not be considered, as the deep-well outfits are as advantageous in developing as in testing wells.

When conditions indicate that a turbine pump should be used for the final plant, manufacturers often agree to install a pump as near the proper size as they can select on the basis of the known conditions. The well is then tested, as in test plan No. 1, by driving the pump with a tractor or other temporary power. Such an arrangement is entered into with the understanding that the manufacturer will add or subtract bowls and column lengths of pipe at specified unit costs and refunds, as required by the conditions brought out by the test. The result of the test will indicate the horsepower needed to drive the pump most economically, and on this basis an engine of correct size should be installed or the belt head replaced with a direct-connected electric motor where electric current is available.

The average well should be developed slowly by controlling the discharge of the test pump with a gate valve. Where sand appears in the water first pumped, the plant should be run with a uniform discharge until the water begins to clear. Then the gate valve can be opened until larger quantities of sand appear in the water, this operation being repeated until the capacity of the pump or well is reached.

When this development process is started, everything should be in readiness so that there will be little likelihood of having to stop the pump before the well has been pumped thoroughly. This is especially desirable when fine sand must be contended with, as stoppage of pumping too soon may cause clogging of the well or pump. In other instances where difficulty is experienced in starting the flow, it may be advisable to fluctuate the discharge in order to agitate the water in the well.

After a well has been pumped for development for several hours to the maximum capacity of the well or of the testing apparatus and there is no apparent fluctuation in the discharge of water, a correct measurement of the flow should be made and the draw down below the static water level noted. The gate valve on the discharge pipe should then be partially closed until the vacuum gauge indicates ap-

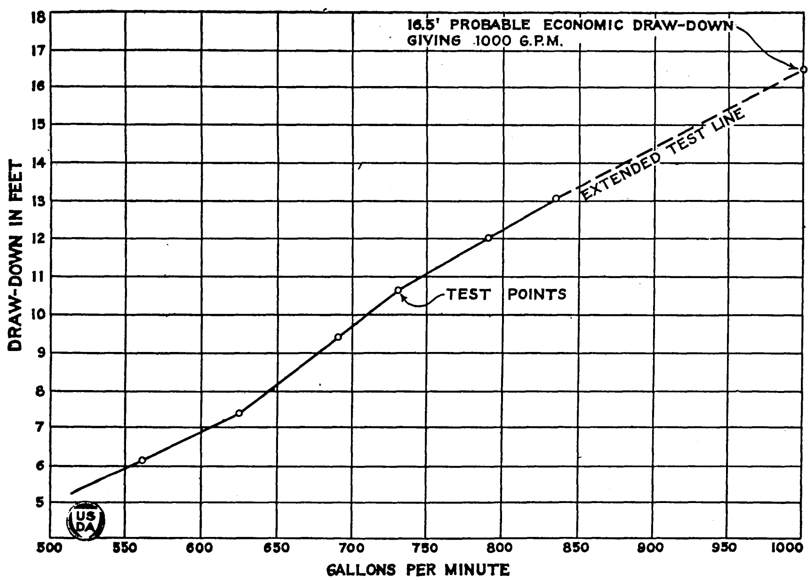

FIG. 1.—Typical well test chart.

proximately 4 feet of draw down below static level. (The vacuum gauge reads in mercury inches and to convert into feet of head the reading should be multiplied by 1.14.) After running about 15 minutes at approximately this level, the discharge and the draw down should be measured accurately and the valve opened until the gauge indicates 6 feet of draw down. This operation should be repeated with 2 feet draw. down intervals until the capacity of the well has again been reached. In this way enough readings may be obtained to indicate the performance of the well at different lifts.

The test should then be plotted graphically on a chart similar to that shown in Figure 1. The vertical scale represents draw down in feet and the horizontal scale discharge in gallons per minute. The rate of increase in flow per foot of draw down is indicated by the general slope of the line connecting the test points plotted on the chart, and the projection of the line beyond the last test point

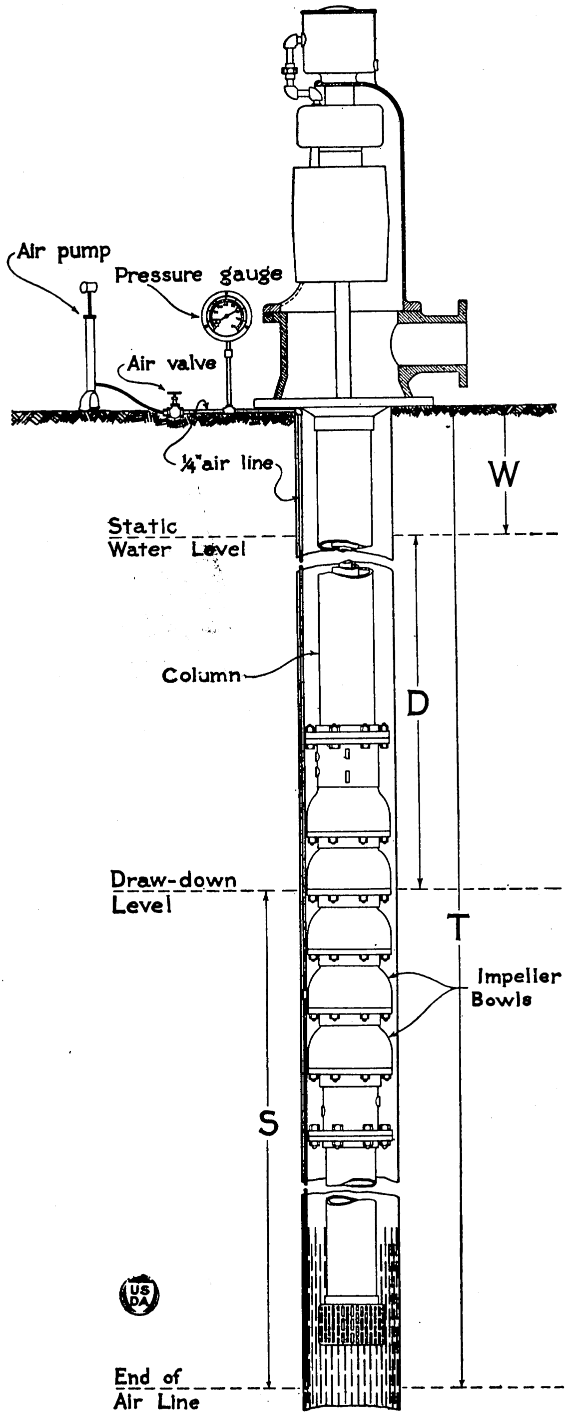

FIG. 2.—Electrically driven deep well turbine pump, showing apparatus for determining draw down.

gives an indication of what may be expected if pumping be continued. In this way a safe economic lift can be assumed and the factors determined which are necessary for the design of machinery to fit the well.

The best way to measure the water is by use of a farmer's weir set, either in a properly designed box or in the bank of a small earthen reservoir made for the purpose.[7]

DETERMINATION OF DRAW DOWN.

When a well is being tested with a centrifugal pump, the draw down can be determined approximately by means of a vacuum gauge placed on the suction ell or flange. The depth of water level below the gauge top may be determined by direct measurement, or from the vacuum gauge after the pump has been primed, unless a foot valve is on the suction pipe. In that case, if it is not feasible to make a direct measurement before the pump is started, the air-line measurement described later is a convenient method of getting

[7] See Farmers' Bulletin 813, Construction and Use of Farm Weirs.

the depth. In any case, the vacuum gauge indicates the draw down below the pump when the latter is discharging water.

Figure 2 illustrates a convenient and accurate way to determine the draw down where a test is made with a turbine pump. A one-quarter inch air tube of known length is placed in the well alongside the turbine. This tube should be long enough to reach below the level of the probable maximum draw down. To the upper end of the air line are attached a pressure gauge, an automobile inner tube valve or one similar, and a hand air pump, in such a way that all the water can be forced out of the tube and the air pressure necessary to do this read on the gauge. The gauge reading indicates the depth of the tube's submergence, and this, when converted into feet of head and subtracted from the total length of the tube, gives the depth to water below the pump at any stage of the test.

The following equations should be used in the test (see fig. 2):

Let T = Total length air tube in feet.

W = Depth in feet to static water level.

D = Draw down, in feet, at any stage of test to correspond with G.

S = Depth in feet to which air line is submerged.

G = Pressure-gauge reading, in pounds per square inch, at any stage of test.

(1) Then $T=W+D+S$.

(2) $D=T-W-S$.

As 1 pound pressure (gauge reading) = 2.31 feet of head,

(3) Then $S=2.31\ G$.

(4) Substituting, $D=T-W-2.31\ G$.

When the pump is not running, D=zero, and W can be determined by

(5) $W=T-2.31\ G$.

For example, and referring again to Figure 2, it is assumed that the total length of air line, T=100 feet. Then to determine the distance to static water level, W, before the test is started, all water should be forced from the air line by use of the air pump, causing a gauge reading, G=say, 34½ pounds per square inch.

Substituting values for T and G in equation (5)

$$W=100-2.31\times 34.5=20.30 \text{ feet}$$

To determine the ultimate draw down or the draw down at any stage of the test: The water is forced from the air line as in the preceding example and the pressure gauge G is read. It is assumed that the reading is 21.5 pounds per square inch.

Substituting values for T, W, and G in equation (4)

$$D=100-20.30-2.31\times 21.5=30.04 \text{ feet}$$

Should this value of D equal the ultimate draw down in a test, then the total lift in the well would be $D+W=30.04+20.30=50.34$ feet, and this value would be used in designing the plant.

BATTERY OF WELLS.

A battery of wells consists of several wells connected to a central pumping unit. This method is applicable where natural conditions limit the ground water available for pumping to one or two shallow strata of sand which give up water very slowly. This method is limited further to formations which carry a fairly constant ground-water table in order to avoid the necessity of lowering and raising the pump unit to keep the pump within suction limits.

In this instance the central pump unit is a horizontal centrifugal pump on or near the surface where the ground-water level is constant and is within 20 feet or so of the surface at full draw down; or this unit may be placed in a central pit to a depth usually not greater than 20 feet where the water level while pumping recedes to 30 or 35 feet from the surface. Usually the suction line which connects the several wells to the central pumping unit is laid in a trench or a tunnel just above the water table at maximum level. The pump is primed by means of an air pump connected with the top of the pump shell. Great care must be exercised to prevent air leaks in any part of the suction line.

Ordinarily the battery of wells is located in a straight line along the boundary fence at the upper end of the land to be irrigated. Water enters the wells from all directions, due to the cone of depression in the ground-water table when the pump is operating; hence it is seldom necessary to place the line of wells at right angles to the line of flow of the ground water.

Where water under pressure may be developed from deep formations and released into a porous stratum it may be elevated to the surface by means of a deep-well pump which is designed to take care of considerable variation of ground-water level. This method of ground-water development has replaced to a great extent the battery method formerly used in several sections of the West.

PUMPS.

The horizontal and vertical centrifugal, the deep-well turbine centrifugal, and the plunger and air-lift pumps are the types most commonly used and best adapted to raising water from wells for irrigation.

HORIZONTAL CENTRIFUGAL TYPE.

Usually the horizontal centrifugal pump (fig. 3) is the cheapest in first cost and operation and the most reliable. Further advantages are: Comparatively light weight, lack of valves and parts that wear out rapidly, simple operation and maintenance, and high efficiency in raising large quantities of water through moderate lifts. It is especially adapted to pumping 250 gallons per minute or more where the suction lift is not over 20 feet and for pumping from a battery of wells when the lift is low. A centrifugal pump can not be operated when submerged, and it can not be used where the change of water level due to pumping exceeds 20 feet, the practical limit of suction lift, unless it is placed in a waterproof pit below the static water level. If the draw down of the water during pumping is not more than 40 feet below the ground surface, this pump can be installed in a pit and direct-connected to an electric motor or belt-connected to engine or motor at the ground surface. Fifteen feet is usually considered the maximum depth of pit for this type of pump when belt-driven.

When the total lift exceeds from 100 to 150 feet, the horizontal and the vertical centrifugal type described later are usually "staged." Staging means the multiplication of runners or impellers, each of which repeats the work of the preceding one, the combination being capable of forcing the water through much higher lifts than can be done with a single-stage pump.

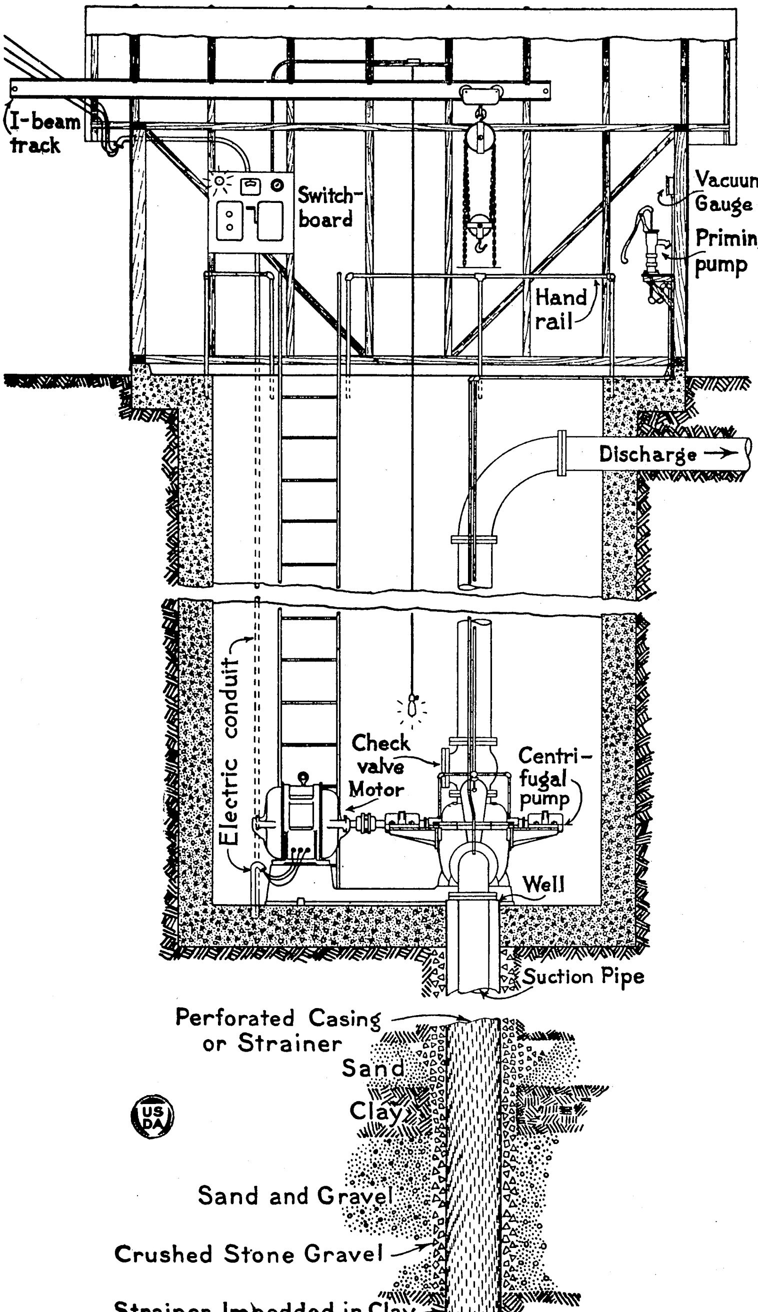

FIG. 3.—Electrically driven horizontal centrifugal pump in pit.

To maintain a constant discharge with lowering water level, the speed of the pump must be increased. This generally results in a decreased efficiency unless the runner is changed to fit the altered situation.

VERTICAL CENTRIFUGAL TYPE.

The vertical centrifugal type differs from the horizontal type in that the impeller is operated by a vertical shaft, which may be of considerable length. Many early wells in locations favorable for pumping were of 10-inch diameter, and this type of pump was especially adapted to such conditions if the lift did not exceed 50 feet. The pump is set in the bottom of a pit below water level and is driven by an electric motor or engine belt-connected to a pulley at the top of the shaft on the ground surface or, it may be, operated by a direct-connected vertical electric motor. The vertical shaft must be supported by a framework to prevent excessive vibration.

The chief advantage of a vertical over a horizontal pump is that it may be used with an internal-combustion engine for higher lifts, since the length of belt between pump and engine pulleys need never be excessive and a belt-way need not be built. This pump may be used where the water level fluctuates more than 20 feet, since it may be placed near or below the level of greatest draw down. In fact, the pump is usually submerged to lessen suction lift. On the other hand, the same restrictions as to the depth at which the pump is set due to pit construction apply to the vertical pump. The difficulty of effecting proper lubrication of pump and shaft bearings is likely to be troublesome. Vertical centrifugal pumps cost more than horizontal pumps of the same capacity. To the cost of the pump itself must be added the cost of a rigid framework with bearings to support the vertical shaft, and consideration must be given to the loss of power involved in the operation of the drive shaft, vibration of which is difficult to prevent as the bearings wear. In many sections, the use of this pump for irrigation is giving way to the deep-well turbine centrifugal pump.

DEEP-WELL TURBINE CENTRIFUGAL.

The deep-well turbine centrifugal pump, often called the "turbine" type, is much used in irrigation. It is similar to the vertical centrifugal type in that it has its impellers or runners incased in shells or bowls and is driven with a vertical shaft, which is not, however, supported by a framework. It usually consists of two or more bowls arranged tandem, 12 to 30 feet constituting a stage. (See fig. 2.) The name "turbine" comes from the diffusion vanes which guide the water from impeller to impeller. The principles of operation of this pump are the same as those previously described. The chief differences are its compactness and its adaptability to insertion in cased wells at considerable depths. Wells 10 inches in diameter and even smaller may be pumped, but with less efficiency than in the larger sizes, which occasionally are 24 inches in diameter or more. If the capacity of the well justifies a larger pump than will go into the well, the upper part of the casing is enlarged as far down as is necessary to accommodate the bowls and the suction is extended into the smaller casing, or in certain instances attached directly to screw casing. It is especially adapted to lifts varying from 50 to 250 feet.

The deep-well turbine pump has an advantage over the horizontal and vertical centrifugals in that it is far less restricted as to lift. Lubrication being effected from the ground surface, the depth at which the pump is set is limited neither by the expense of pit construction nor difficulty in attendance, but only by the cost of operation and by mechanical limitations of the pump itself. High lifts and large volumes of water are handled without difficulty. As in the case of the vertical centrifugal, the turbine pump is operated by means of an engine or motor at the ground surface belted to a pulley on the vertical shaft or is direct connected to a vertical motor incorporated in the pump head.

The turbine type is more expensive than either the horizontal or vertical centrifugal pump. It is not adaptable to pumping from two or more wells simultaneously. It is generally efficient and gives little trouble when properly installed. It is best suited to installations where the water level is more than 50 feet below the ground surface or in other circumstances where the water level fluctuates widely. Its principal disadvantage, besides its comparatively high first cost, lies in the expense and difficulty of making repairs, which usually involve the withdrawal of the entire pump from the well.

Manufacturers are likely to emphasize the ease with which this pump may be lowered to meet the requirements of a lowered water table, but this usually requires the installation of additional bowls or stages necessitating the removal of the entire pump from the well. Consequently, the expense of reassembling the pump and fitting additional bowls or stages should be considered in making a selection.

PLUNGER TYPES.

The plunger pump commonly used on the farm to raise water for domestic purposes may be utilized in irrigating very small areas. The plunger pump generally used and probably best adapted to pumping from wells consists of a brass cylinder in which operate two plungers with valves. (See fig. 4.) The lower plunger is connected to a solid rod which fits into a hollow rod to which the upper plunger is connected. The plungers are operated in such a way as to make the pump double-acting, one plunger being on its down stroke while the other is moving upward, so producing a fairly continuous discharge. Above the cylinder, and connected to it, is the vertical discharge pipe through which the water is forced by the action of the plungers. The pump is set in the casing with the plungers under water. At the surface of the ground the pump rods are attached to and driven by a power head, through gears, levers, or eccentrics. The power head, in turn, is driven by a motor or engine. The size of the cylinders ranges from 6 to 16 inches in diameter and the number of strokes varies from 16 to 24 per minute, ranging in length from 28 to 36 inches. By ingenious devices in some makes the downward stroke of each plunger is faster than the upward stroke. There is thus a lap in the strokes of the two plungers which does away with the tendency, otherwise present, for the flow of water to diminish when the two plungers are on dead center. A desirable feature of recent models is the sliding rail base on which the working head is built.

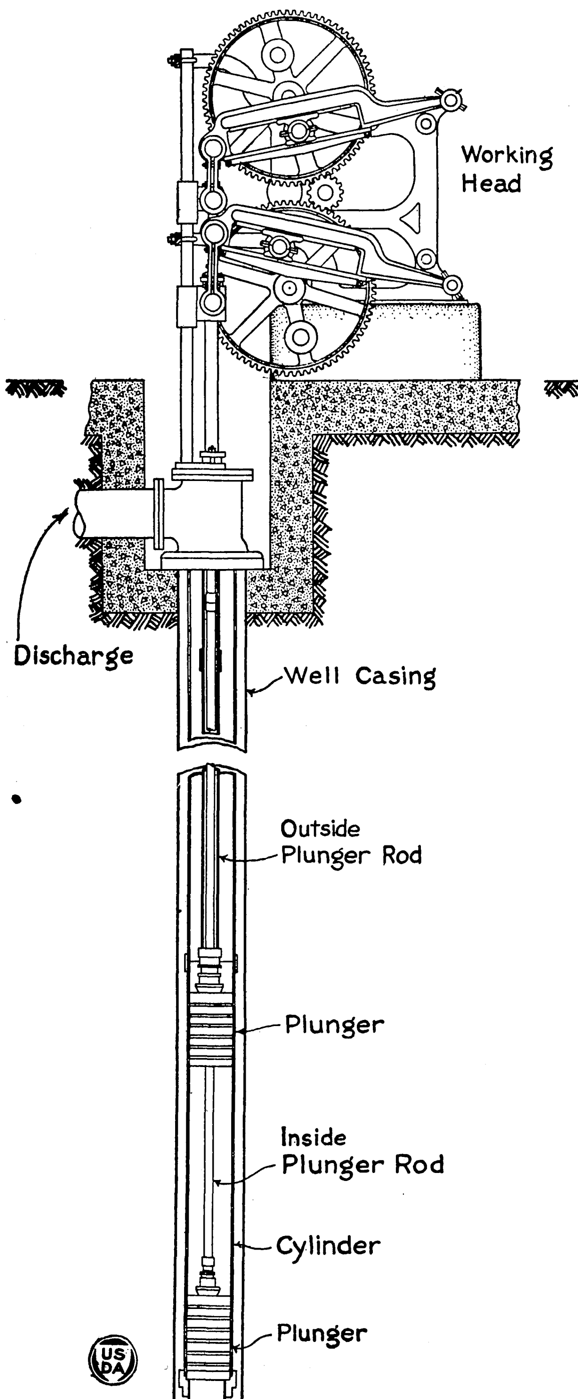

FIG. 4.—Electrically driven deep well plunger pump.

This permits the machinery to be slid back out of the way when the plungers or cylinder must be pulled.

The plunger pump is best adapted to irrigation where comparatively small quantities of water must be raised from great depths. When first installed, it has the highest efficiency of any pump, and under favorable conditions, if properly cared for, gives little trouble. On the other hand, its first cost is high. The leathers, valves, and cylinders wear quickly where sandy water is pumped, and if high efficiency is to be maintained, repairs must be made at considerable expense and loss of time. This type has its widest use in the irrigation of orchards in southern California, where small quantities of water are pumped against very high heads at an expense warranted only by the value of the irrigated crops grown there.

AIR LIFT.

The simplest type of air lift consists of a discharge pipe which is inserted into the well to a depth below the water surface of at least twice the vertical distance of the water from the ground surface; an air pipe extending from a compressor to the bottom of the discharge pipe and connected to it by a casting specially designed to distribute the air evenly; and a tailpiece which forms a slightly enlarged extension of the lower end of the discharge pipe below the point where air is admitted. The compressor forces the air deep into the water, where it is released and rises to the surface, forcing a quantity of water up with it.

The absence of complicated working parts beneath the surface of the ground is an outstanding advantage of the air lift. Sand and other material may be removed with the water without harm to the pump. If proper submergence is possible the pump may be adjusted to a lowering water level, and is particularly adapted to pumping several wells from a central power house. An air-lift pump is also adapted to a crooked well in which a turbine pump can not be set.

The air-lift pump is relatively costly because of its power unit. Depreciation and fixed operating charges are low, but the efficiency is also low, and because of the low efficiency this type of plant is not well adapted for pumping for irrigation except under special conditions, such, for instance, as a number of deep wells in close proximity to each other, all having sufficient depth of water to afford proper submergence.

OTHER TYPES.

The pumps already described are those chiefly used in irrigation from wells, and it is advisable to go slowly in the purchase of any new and untried type, no matter what the principle of operation may be. Improvements constantly are being made in pumping apparatus, but the advantages of innovations should be demonstrated and well understood before they are adopted.

SELECTION, INSTALLATION, AND OPERATION OF PUMPS.

Under ordinary circumstances the horizontal centrifugal type is best adapted to lifts of 50 feet or less. If electric power is not available, 40 feet is usually considered the maximum lift for the horizontal centrifugal. Lifts from 50 to 75 feet may be managed by vertical centrifugal or turbine pumps as particular conditions may direct. The turbine pump is best adapted to lifts from 75 to 150 feet. There is a range between 150 and 250 feet where selection is possible between turbine and plunger types, but the deep-well turbine centrifugal type is best for pumping large quantities of water within this range of lifts. The plunger pump is to be considered when the depth to the water is great and the quantity of water to be pumped is not more than 500 gallons per minute. The air lift is restricted neither as to lift nor quantity of water to be pumped, but its low efficiency should limit its use to the special conditions already mentioned.

All three types of centrifugal pumps should be ordered to fit given conditions of lift and capacity. Too often the only condition stipulated by the farmer ordering a horizontal or vertical centrifugal pump is that it discharge a specified quantity of water, but it should be remembered that it is possible to obtain widely varying quantities of water from a centrifugal or turbine pump by varying the speed of its operation. Hence an unscrupulous pump dealer can convey a false impression as to the capacity of a pump by forcing it to an uneconomical and inefficiant speed. There is only one set of conditions of discharge and speed under which centrifugal pumps will operate for a given head at maximum efficiency. A pump bought in ignorance of this fact, with cheapness as the main consideration, will prove more costly in the long run than the more expensive but efficient pump.

The approximate capacities and efficiencies of different sizes of centrifugal pumps (not including the turbine type) are given in Table 1. In ordinary practice a good pumping plant, properly installed, should easily reach the efficiency shown.

TABLE 1.—*Typical capacities of centrifugal pumps and horsepower required for their operation under average conditions.*[1]

No. of centrifugal pump.	Discharge per minute.	Theoretical horsepower per foot of lift.	Efficiency.	Actual horsepower per foot of lift.[2]	No. of centrifugal pump.	Discharge per minute.	Theoretical horsepower per foot of lift.	Efficiency.	Actual horsepower per foot of lift.[2]
	U. S. gals.		*Per cent.*			*U. S. gals.*		*Per cent.*	
2	100	0.025	40 to 45	0.06	5	700	0.175	62 to 66	0.28
2½	150	.038	45 to 50	.08	6	900	.225	66 to 68	.34
3	225	.056	50 to 55	.11	7	1,200	.300	68 to 70	.44
3½	300	.075	55 to 60	.14	8	1,600	.400	70 to 74	.57
4	400	.100	60 to 62	.17					

[1] Above efficiencies are for pumps properly designed and installed for heads of 40 to 60 feet. Plant efficiencies can be estimated by subtracting 10 per cent for direct-connected electric motors and 17 to 22 per cent for belt-connected power.
[2] Efficiencies taken as the lower in preceding column.

The amount of power lost in forcing a given quantity of water through a pipe varies with the length, size, and kind of pipe, the number and sharpness of bends, and the valves and other obstructions to flow. When a bend must be made in the discharge or suction pipe, a long-radius elbow should be used if possible. The suction pipe must be air-tight and should extend at least 20 feet below the level to which water will be drawn. The discharge pipe should be carried no higher than necessary, as each foot in height increases the cost of pumping.

Unlike centrifugal pumps, the discharge of the plunger pump can be varied by changing the speed without any sacrifice of efficiency. It should not, of course, be operated at a speed which will cause excessive wear. In order to reduce friction loss, suction and discharge pipes should be of sufficient size and have as few short bends as possible. This is likewise true of air-lift pumps. The discharge pipe or column of the air-lift pump should be large enough to keep the velocity of the water below 5 feet per second.

POWER UNIT.

Ample power must be available to operate a pumping plant without overloading the engine or motor. As a precaution the plant should be designed to meet a load 10 per cent greater than the estimated requirement. The power necessary to lift water is measured in horsepower. One theoretical horsepower represents the energy required to lift 33,000 pounds 1 foot high in 1 minute.

Table 2 shows the actual horsepower needed to lift different quantities of water to elevations of 10 to 300 feet, assuming the efficiency of the plant to be 50 per cent. Oil engines and motors usually are rated on brake horsepower. Engines and motors manufactured by reputable firms will deliver their rated horsepower, and in emergencies motors are generally good for a small overload for a short run; but it is never wise deliberately to overload either oil engines or motors, as difficulties in operation are almost certain to follow.

TABLE 2.—*Horsepower required to lift different quantities of water to elevations of 10 feet to 300 feet.*

[Efficiency of pumping plant, 50 per cent of theoretical. Use for estimating purposes only.]

Gallons per minute.	Cubic feet per second.	Elevation in feet.															
		10 h. p.	20 h. p.	30 h. p.	40 h. p.	50 h. p.	60 h. p.	70 h. p.	80 h. p.	90 h. p.	100 h. p.	125 h. p.	150 h. p.	175 h. p.	200 h. p.	250 h. p.	300 h. p.
250	0.56	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	15.62	18.75	21.88	25.00	31.25	37.50
300	.67	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	18.75	22.50	26.25	30.00	37.50	45.00
350	.78	1.75	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.75	17.50	21.88	26.25	30.62	35.00	43.75	52.50
400	.89	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	25.00	30.00	35.00	40.00	50.00	60.00
450	1.00	2.25	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	28.12	33.75	39.38	45.00	56.25	67.50
500	1.12	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	31.25	37.50	43.75	50.00	62.50	75.00
600	1.34	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00	37.50	45.00	52.50	60.00	75.00	90.00
700	1.56	3.50	7.00	10.50	14.00	17.50	21.00	24.50	28.00	31.50	35.00	43.75	52.50	61.25	70.00	87.50	105.00
800	1.78	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	50.00	60.00	70.00	80.00	100.00	120.00
900	2.01	4.50	9.00	13.50	18.00	22.50	27.00	31.50	36.00	40.50	45.00	56.25	67.50	78.75	90.00	112.50	135.00
1,000	2.23	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	62.50	75.00	87.50	100.00	125.00	150.00
1,250	2.78	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	78.12	93.75	109.38	125.00	156.25	187.50
1,500	3.34	7.50	15.00	22.50	30.00	37.50	45.00	52.50	60.00	67.50	75.00	93.75	112.50	131.25	150.00	187.50	225.00

Lifts and quantities may be derived from the following formula:

$$\text{Horsepower} = \frac{g.p.m. \times h}{4{,}000 \times E}$$

Where *g. p. m.* = Gallons pumped per minute.
h = Total head in feet against which pump must work. This includes the total vertical lift, plus frictional and other losses.
E = The efficiency of the pump.

The horsepower in this instance is the power applied at the pump pulley. The efficiency usually specified by the pump manufacturer is the *E* used in this formula. It must be kept in mind that friction caused by the movement of the water in the suction and discharge pipes, and obstructions to the flow caused by bends, valves, etc., offer further resistance which must be overcome by the pump. These losses converted to feet of additional height through which the water must be lifted, are taken into account in the *h* in the above formula. In Table 2, the horsepower of the engine or motor specified is taken as twice the horsepower theoretically required, this being the usual practice with pump manufacturers. However, as indicated in Table 1, the value of *E* increases with the size of the pump.

THE ELECTRIC MOTOR.

Where electric current is obtainable at reasonable cost, it is the most satisfactory source of power for irrigation pumping. Electric motors combine reasonably low cost, safety, high efficiency, reliability, and ease of operation.

The range of speed in the various sizes of electric motors is such that they are readily adapted to the operation of pumps. The electric motor, not requiring constant attention, may be direct connected to the pump shaft, so eliminating friction and slippage losses due to transmission through gears or belts.

Direct-connected electric plants are compact and require less housing than plants of other types, and avoid the trouble of purchasing, hauling, and storing fuel. The following rates are charged by a California company supplying current to many pumping plants. They give a fair idea of the cost of such service.

TABLE 3.—*Rates charged for electricity.*

Size of installation (horsepower).	Annual demand charge per horsepower.	Energy charge in addition to the demand charge; rate per kilowatt hour for consumption per horsepower per year of—			
		First 1,000 kilowatt hours.	Next 1,000 kilowatt hours.	Next 1,000 kilowatt hours.	All over 3,000 kilowatt hours.
	Dollars.	*Cents.*	*Cents.*	*Cent.*	*Cent.*
2 to 4	[1] 6.60	1.6	1.2	0.9	0.7
5 to 14	6.00	1.4	1.1	.8	.7
15 to 49	5.40	1.2	1.0	.8	.7
50 to 99	4.50	1.1	.9	.75	.7

[1] In no case will the total annual demand be less than $13.20.

Any consumer may select at his option the following rate instead of the demand and energy rate set forth above:

Horsepower of connected load.	Annual minimum charge per horsepower.	Rate per kilowatt hour for consumption per horsepower per year of—				
		First 300 kilowatt hours.	Next 700 kilowatt hours.	Next 1,000 kilowatt hours.	Next 1,000 kilowatt hours.	All over 3,000 kilowatt hours.
	Dollars.	*Cents.*	*Cents.*	*Cents.*	*Cent.*	*Cent.*
2 to 4	[1] 9.00	3.8	1.6	1.2	0.9	0.7
5 to 14	8.00	3.4	1.4	1.1	.8	.7
15 to 49	7.50	3.0	1.2	1.0	.8	.7
50 to 99	7.00	2.6	1.1	.9	.75	.7

[1] In no case will the total minimum charge be less than $27 per year.

Some companies supply current at flat monthly rates, and one such enterprise, to encourage continuous use of power, quoting its rates upon "the connected load in motors or other utilization equipment which can be connected at any one time to the company's supply system," allows the consumer to use electric energy, under certain conditions, for operating small motors to cut alfalfa or other feed, grind corn, operate cream separators, pump water for domestic purposes or for stock, or for like purposes.

Where electric power is to be utilized, frequently several miles of power line must be provided in order to tap the main line of some large power company, and secondary lines must be constructed to each pumping plant. The cost of these power lines, especially when they are long, is an important item in the cost of pumping plants. Ordinarily it is met at first by the consumer; but some companies divide it with their customers or refund it in service.

THE INTERNAL-COMBUSTION ENGINE.

Internal-combustion engines are efficient and with proper care will continue to be so through a comparatively long life. This is especially true of the Diesel and semi-Diesel types, which are ordinarily adapted, however, only to installations of large size. It is commonly regarded that an engine will last from 8 to 12 years. Some farmers pump water only a few days per week or only a few hours per day, others operate their plants continuously day and night, and the length of the irrigation season varies widely in different localities; hence the life of an engine used to operate a pumping plant can not be estimated closely in years. Its life in hours depends upon three factors: The quality of metal and workmanship put into its manufacture, the load it operates under, and the attention given to its operation, and the fuel used. The first factor is of interest to a purchaser, but internal-combustion engines usually are well built and are delivered in good condition.

A heavily loaded engine will not last as long as one lightly loaded, a load of 75 to 80 per cent of the rating of the engine usually being the safe maximum. A substantial foundation is necessary to reduce vibration; and the distance between, comparative elevations, and alignment of pump and engine pulleys should be such as to avoid belt trouble. Instructions regarding these matters are furnished by the pump or engine company from which the purchase is made. An engine should have a good sight-feed lubrication and an ample cooling system. Poor lubricating oil should not be used. Proper housing of an engine is important, particularly in a country where freezing weather or sandstorms occur. The housing should be as nearly dustproof as possible. Dust, dirt, grime, rain, and neglect cause rapid depreciation. Every engine should be cleaned at regular intervals, and bolts, springs, valves, and other parts should be examined and necessary repairs made.

Suitability of fuel is a big factor. One obstacle to the continued use of the internal-combustion engine for pumping in recent years has been the uncertainty about securing a supply of fuel oil at prices making its use practical, and it is well to select an engine which will run on more than a single grade of oil. An engine using the heavier grades of oil had best be chosen, since it will work with the lighter oils when the cheaper grades are not available. However, it is false economy, when proper oil is available, to try to burn cheap oils which are too heavy or contain too much asphalt.

Clean combustion is very important in prolonging the life of an engine. A smoky exhaust indicates a foul, dirty cylinder, injurious deposits, and rapid wear. Engine performance depends principally on the condition of cylinders and piston rings; other parts can be maintained in good order with occasional small expenditures.

Difference in atmospheric pressures causes a difference in power produced by engines, and although this is not large it should be taken into account where installations are made at considerable heights above sea level.

COST OF PUMPING INSTALLATION.

It is beyond the scope of this bulletin to give costs of pumping-plant installations in such detail that they will be generally applicable throughout the irrigated region. In order that the prospective purchaser may have clearly in mind the items which usually enter into the cost of pumping plants, estimates of the cost of plants of the three types in most common use are given. Conditions peculiar to different communities will qualify these estimates and the cost reported should be considered as suggestive only. Before a plant is purchased, quotations on the equipment it is proposed to install should be secured from reliable dealers. In each of the three types described the cost of the transmission line is omitted for reasons stated on page 22. The reader should ascertain what expense would be involved in bringing electrical current to his farm from the nearest power main and what refunds would be made in case the initial expense were charged to him, amending this estimate accordingly.

Case No. 1.

Electrically-driven centrifugal pump in pit. (See fig. 3.)

Conditions:
- Crop to be irrigated, alfalfa.
- Depth of water required on land, 3 feet in six irrigations, in a 30-day rotation in 6-inch applications.
- Amount of water furnished by well, 2 second-feet=900 gallons per minute, which will irrigate 4 acres 6 inches deep each 12 hours or 120 acres in thirty 12-hour days or fifteen 24-hour days.
- Lift of water=40 feet.
- Theoretical horsepower, 9.
- Plant efficiency, 60 per cent.
- Motor required, 15 h. p.

Cost of plant:		
Well 100 feet deep, drilling at $2 per foot	$200.00	
Casing, 12-inch double stovepipe, 12 gauge, 60 feet, at $2.25	135.00	
Casing starter 20-foot, 3-ply, and ring	90.00	
Pit, 8 by 8 by 25 feet inside; concrete 6-inch walls and bottom, at $15 per foot depth	375.00	
Total		$800.00
Pump No. 6 single stage horizontal centrifugal, direct-connected to 15 horsepower electric motor, installed with necessary electric and hydraulic accessories	900.00	
Pump house with overhead lifting device, concrete floor, pit railing, etc	400.00	
Total		1,300.00
Total cost of plant		2,100.00
Cost per acre ($1,200÷120)		17.50
Cost of operation per season:		
Interest on $2,100 at 7 per cent	147.00	
Taxes and insurance at 1 per cent	21.00	
Depreciation of machinery (value $900) at 10 per cent	90.00	
Depreciation of house and well (value $1,200 at 5 per cent	60.00	
Power consumed, 11.2 kilowatts for 2,160 hours at 2 cents per kilowatt hour	483.84	
Repairs, lubricating oil and attendance, per season	50.00	
Total cost of operating per season		851.84
Cost of pumping per acre season ($851.84÷120)		7.10
Cost of pumping per acre-foot of water ($7.10÷3)		2.37

Centrifugal pump in pit, driven by oil engine.

It is estimated that the plant described in Case 1 could be installed with a 15-horsepower oil engine, necessary changes being made in pit and house design, at an approximate cost of	$2,800.00
Cost per acre for oil engine plant ($2,800÷120)	23.33

Cost of operating with oil engine.

Interest on $2,800 at 7 per cent	$196.00	
Taxes and insurance at 1 per cent	28.00	
Depreciation of machinery (value $1,600) at 10 per cent	160.00	
Depreciation of house, well and pit (value $1,200) at 5 per cent	60.00	
Fuel consumed 1½ gallons 24-gravity oil per hour for 2,160 hours, at 5 cents per gallon	162.00	
Repairs, lubricating oil, and attendance per season	150.00	
Total cost of operating per season		$756.00
Cost of pumping per acre per season ($756÷120)		6.30
Cost of pumping per acre-foot of water ($6.30÷3)		2.10

CASE No. 2.

Electrically-driven, deep-well turbine pump. (See fig. 2.)

Conditions:
- Crop to be irrigated, fruit.
- Depth of water required on land, 1.5 feet in three irrigations, in a 60-day rotation of 6-inch applications.
- Amount of water furnished by well, 1 second-foot=450 gallons per minute, which will irrigate 2 acres 6 inches deep each 12 hours or 120 acres in sixty 12-hour days.
- Lift, 100 feet.
- Theoretical horsepower, 11.25.
- Plant efficiency, 50 per cent.
- Motor required, 25 horsepower.

Cost of plant:		
Well 200 feet deep, drilling at $2 per foot	$400.00	
Casing, 12-inch double stovepipe, 12 gauge, 180 feet at $2.25	405.00	
Casing starter 20-feet, 3-ply, and ring	90.00	
Cost of well, total		$895.00
Pump, deep-well turbine installed on concrete base with direct-connected vertical 25-h. p. motor	1,500.00	
Electric protection accessories	200.00	
Pump house, 8 by 8 by 7 feet posts	100.00	
Cost of pumping plant installed, total		1,800.00
Total cost of plant		2,695.00
Cost of plant per acre ($2,695÷120)		22.46
Cost of operation per season:		
Interest on $2,695 at 7 per cent	188.65	
Taxes and insurance on $2,695 at 1 per cent	26.95	
Depreciation of machinery (value $1,700) at 10 per cent	170.00	
Depreciation of well and building (value $995) at 5 per cent	49.75	
Power consumed, 16,785 kilowatts for 2,160 hours at 2 cents per kilowatt hour)	725.11	
Repairs, lubricating oil, and attendance per season	100.00	
Total cost of operation per season		1,260.46
Cost of pumping per acre per season ($1,260.46÷120)		10.50
Cost of pumping per acre-foot of water ($10.50÷1.5)		7.00

Deep-well turbine pump driven by oil engine.

It is estimated that the plant described in Case 2 could be installed with a 25-horsepower oil engine, enlarged pump house, and foundation for approximately		$3,700.00
Cost per acre of oil-engine plant ($3,700÷120)		30.83

Cost of operating per season with oil engine.

Interest on $3,700 at 7 per cent	$259.00	
Taxes and insurance on $3,700 at 1 per cent	37.00	
Depreciation of machinery (value $2,600) at 10 per cent	260.00	
Depreciation of well, pump house, etc. (value $1,100) at 5 per cent	55.00	
Fuel consumed, 2½ gallons per hour for 2,160 hours, at 5 cents per gallon	270.00	
Repairs, lubricating oil, and attendance per season	300.00	
Total cost of operating per season		$1,181.00
Cost of pumping per acre per season ($1,181÷120)		9.84
Cost of pumping per acre-foot of water ($9.84÷1.5)		6.56

Case No. 3.

Electrically-driven deep-well plunger pump. (See fig. 4.)

Conditions:
- Crop to be irrigated, apples or citrus orchards.
- Depth of water required on land, 1.5 feet in three irrigations, in a 60-day rotation of 6-inch applications.
- Amount of water furnished by well, one-half second-foot=225 gallons per minute, which will irrigate 1 acre 6 inches deep each 12 hours, or 60 acres in sixty 12-hour days.
- Lift, 200 feet.
- Theoretical horsepower, 11.2.
- Plant efficiency, 70 per cent.
- Motor required, 20 horsepower.

Cost of plant:

Well 300 feet deep, drilling at $2 per foot	$600.00	
Casing, 12-inch double stovepipe, 12 gauge, 280 feet at $2.25 per foot	630.00	
Casing starter, 20 feet, 3-ply, and ring	90.00	
Total cost of well		$1,320.00
Pump, double-acting, deep-well, working head on slide rails, connected to 20-horsepower electric motor by short belt and idler or silent chain, 8-inch cylinder, 195 feet of column pipe, and double plunger rods, complete	$2,300.00	
Motor, 20 h. p., with protection accessories	550.00	
Derrick, with windlass and pump house	400.00	
Installation, labor, concrete foundation, freight, etc	650.00	
Cost of pumping plant installed		3,900.00
Total cost of plant		5,220.00
Cost of plant per acre ($5,220÷60)		87.00

Cost of operation:

Interest on $5,220 at 7 per cent	$365.40	
Taxes and insurance at 1 per cent	52.20	
Depreciation of machinery (value $3,500) at 10 per cent	350.00	
Depreciation of well and pump house (value $1,720) at 5 per cent	86.00	
Power consumed, 12.1 k. w. 2,160 hours at 2 cents per k. w. hour	522.72	
Repairs, lubricating oil, and attendance per season	100.00	
Total cost of operating per season		1,476.32
Cost of pumping per acre per season ($1,476.32÷60)		24.61
Cost of pumping per acre foot of water ($24.61÷1.5)		16 41

Deep-well plunger pump, driven by oil engine.

It is estimated that the plant described in Case 3 could be installed with a 20-horsepower oil engine, an enlarged pump house, belt, and foundation for approximately	$5, 900. 00
Cost per acre of oil engine plant ($5,900÷60)	98. 33

Cost of operating with oil engine.

Interest on $5,900 at 7 per cent	$413. 00	
Taxes and insurance on $5,900 at 1 per cent	59. 00	
Depreciation of machinery (value $4,080) at 10 per cent	408. 00	
Depreciation of well, building, etc. (value $1,820), at 5 per cent	91. 00	
Fuel consumed, 2 gallons per hour for 2,160 hours at 5 cents per gallon	216. 00	
Repairs, lubricating oil, and attendance per season	250. 00	
Total cost of operating per season		$1, 437. 00
Cost of pumping per acre per season ($1,437÷60)		23. 95
Cost of pumping per acre foot of water ($23.95÷1.5)		15. 97

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